SUPREME COURT OF THE STATE OF NEW YORK
COUNTY OF NEW YORK

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| IN RE NEW YORK COUNTY ASBESTOS LITIGATION | NYCAL<br>I.A.S. Part 11<br>(Madden, J.) |
| This document Relates to:<br>CHRISTIAN F. HOLINKA<br><br>Plaintiff,<br><br>-against-<br><br>A.W. CHESTERTON COMPANY, et al.,<br><br>Defendants. | Index No. 114120-06<br><br>**AFFIDAVIT OF TIMOTHY J. FRASER** |

STATE OF NEW JERSEY )
) ss:
COUNTY OF MORRIS )

Timothy J. Fraser, being duly sworn, deposes and says:

1. I am an attorney at law of the State of New York and am an associate at the law firm of Drinker Biddle & Reath LLP, attorneys for defendant Baxter Healthcare Corporation . I am over the age of eighteen and I am not a party to this action. I have personal knowledge of the facts set forth herein.

3. Exhibit A is a true and complete copy of "National Research Council, *Human Exposure Assessment for Airborne Pollutants: Advances and Opportunities* (1991)."

4. Exhibit B is a true and complete copy of "Department of Health and Human Services, *Exposure Assessment Methods: Research Needs and Priorities* (July 2002)."

5. Exhibit C is a true and complete copy of plaintiff's Expert Witness Disclosure Pursuant to CPLR 3101(d).

6. Exhibit D is a true and complete copy of the *curriculum vitae* of Sheldon H. Rabinovitz, Ph.D., C.I.H.

Timothy J. Fraser

Sworn to and subscribed before me on
this 10th day of September, 2007

Patricia M. Ioannou
Notary Public

PATRICIA M. IOANNOU
NOTARY PUBLIC
STATE OF NEW JERSEY
MY COMMISSION EXPIRES FEB. 17, 2010

Exhibit A

# Human Exposure Assessment for Airborne Pollutants

## *Advances and Opportunities*

Committee on Advances in Assessing
Human Exposure to Airborne Pollutants

Board on Environmental Studies
and Toxicology

Commission on Geosciences,
Environment, and Resources

National Research Council

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1991

# *Executive Summary*

## INTRODUCTION

The Bush Administration and Congress are considering new approaches intended to enhance the public health protection benefits of environmental programs within available resources. One general approach being explored would entail revising some federal strategies and priorities to place greater emphasis upon reducing health risks instead of simply responding to statutory requirements or reacting to public perceptions. Such an approach would need to rely heavily upon the application of scientific knowledge in risk assessments. The success of such an approach would therefore depend upon assessments of human exposures to toxic substances, because the exposure component of a risk assessment often entails greater uncertainty than the hazard component, and because reducing human exposure is directly relevant to reducing health risk for a given toxic substance.

Human exposure to air contaminants is one area in which a risk-reduction-based approach could be beneficial. Traditionally, public concerns about air pollution have focused on highly visible emission sources such as industrial smokestacks and automobiles. Likewise, regulatory strategies mandated by the Clean Air Act have emphasized controlling outdoor sources of air pollution. Since 1970, these strategies have substantially reduced outdoor concentrations for five of the six pollutants for which National Ambient Air Quality Standards have been designated. It is important for these strategies to continue, because exposure to outdoor air pollutants continues to present significant public health risks. For example, outdoor exposures to the sixth pollutant, ozone, still threaten human health in many locations within the United States.

At the same time, air pollutants with major indoor sources are known to cause adverse health effects and personal discomfort, as described in the 1981 National Research Council (NRC) report, *Indoor Pollutants*. In part because the Clean Air Act has been interpreted as applying only to outdoor air, little

progress has been made during the past 20 years in reducing potentially harmful human exposures to air pollutants in many indoor locations. But most people in the United States spend far more time indoors than outdoors; thus risk reduction strategies that address only outdoor air quality are only partially effective. Such strategies need to be modified to better address the importance of indoor exposures.

Benzene (a human carcinogen) provides an example in which the proper application of exposure assessment methodology should be applied to identify areas where more effective strategies are needed to achieve greater reduction of risk. In response to its mandate in the Clean Air Act to control hazardous air pollutants, the U.S. Environmental Protection Agency promulgated regulations in August 1989 for industrial emissions of benzene to outdoor air. However, other large sources of exposure to benzene are not covered by that rulemaking. Exposures from smoking, consumer products in the home, and personal activities such as driving or painting have been estimated to account for more than 80% of nationwide exposure to benzene. Therefore, actual human exposures to benzene at the most significant concentrations and durations are likely to occur inside the home or while traveling within a motor vehicle (i.e., from sources not currently subject to Clean Air Act regulations). The issue of benzene exposure assessment is addressed in Chapter 7, under Volatile Organic Compounds.

The following report describes a conceptual framework and methods for assessing and analyzing the totality of exposures of an individual to air contaminants in the course of all activities over specified increments of time. Accurate and realistic assessment of human exposures from all environmental media can help to ensure that appropriate priorities are set to achieve optimal reduction of human exposures to significant contaminants. Exposure-assessment research should be supported by government programs according to such priorities, commensurate with the importance of human exposures to environmental contaminants, whether outdoors or indoors.

## THE CHARGE TO THE COMMITTEE

The Committee on Advances in Assessing Human Exposure to Airborne Pollutants was established in 1987 by the NRC's Board on Environmental Studies and Toxicology to review important new developments in exposure-assessment methods and instrumentation that have been produced in pollution-related research, occupational medicine, and other disciplines during the past 10-15 years, especially as those developments apply to individual human exposures to airborne toxicants. The committee included members with ex-

pertise in chemistry, mathematical modeling, engineering, physics, air pollution, exposure assessment, medicine, biology, social science, statistics, and environmental policy. The committee's work was sponsored by the Agency for Toxic Substances and Disease Registry of the U.S. Public Health Service, whose mission is to prevent or mitigate adverse human health effects and diminution in quality of life resulting from exposure to hazardous substances in the environment.

The committee was charged to review new developments and developing technologies in exposure assessment, identify technological gaps, and recommend research and development priorities to fill those gaps. The committee was also charged to consider the value of various methods for estimating chemical exposures in risk assessment, risk management, pollution control, and regulatory programs. As part of the information-gathering process, the committee sponsored a 2-day symposium in October 1988, to obtain current information on the uses of exposure analyses, measurement instrumentation, analytical and survey techniques, biological markers, and study design.

## THE COMMITTEE'S APPROACH TO ITS CHARGE

In response to its charge, the committee focused on human exposure to airborne contaminants that can be inhaled or absorbed through the skin and potentially can cause adverse health effects or discomfort for an individual. The committee did not consider in detail exposure to airborne contaminants that come in contact with humans only after the contaminants have transferred to another environmental medium (e.g., deposition of airborne contaminants into food or ingestion of contaminated soil or water). The committee acknowledges that exposure to airborne contaminants is only part of total exposure, which includes all exposures a person has to a specific contaminant; this includes all environmental media (air, water, food, and soil) and all routes of entry (inhalation, ingestion, and dermal absorption). Assessment of total exposure for specified contaminants requires the application of quantitative techniques to all pertinent environmental media and all routes. A single-medium exposure analysis, such as for air only, is appropriate only when supported by convincing evidence that a single-medium exposure predominates for the contaminants of concern.

The committee defines an exposure to a contaminant as an event consisting of contact at a boundary between a human and the environment at a specific environmental contaminant concentration for a specified interval of time; the

units to express exposure are concentration multiplied by time.[1] Exposure assessment involves numerous techniques to identify the contaminant, contaminant sources, environmental media of exposure, transport through each medium, chemical and physical transformations, routes of entry to the body, intensity and frequency of contact, and spatial and temporal concentration patterns of the contaminant. An array of techniques can be employed, ranging from basic techniques for estimating the number of people exposed, to sophisticated methodology employing contaminant monitoring, modeling, and biological markers.

An organizing construct was developed by the committee to facilitate its evaluation of exposure-assessment techniques. The construct specified that techniques be evaluated for their usefulness in reducing the uncertainty about exposures and in reducing the invasiveness of the measurement techniques, while improving the efficiency of ways to obtain data on the concentration and duration of contaminant contact with the individual or population. Exposure of the individual was considered key, because the committee determined that knowledge of such exposures is essential to make inferences about the general population.

The committee recognized that good exposure-assessment techniques do not guarantee meaningful exposure data; techniques must be applied properly. Therefore, exposure-assessment techniques also were considered for their appropriateness in obtaining data within a scientifically sound conceptual framework for exposure assessment. The conceptual framework for exposure assessment defined by the committee is illustrated in Chapter 7 with a series of critical analyses of the ways in which exposure assessments could be and have been applied to specific public-health concerns. It was not within the committee's charge to address in detail the proper application and further development of techniques to assess exposure to specific contaminants.

## RATIONALE FOR PERFORMING EXPOSURE ASSESSMENTS

Exposure assessment is an integral component of environmental epidemiology, risk assessment, risk management, and disease diagnosis and treatment. It is a multidisciplinary endeavor that frequently requires the combined exper-

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[1]Confusion often occurs with the use of the terms "exposure" and "dose." Dose is the amount of contaminant that is absorbed or deposited in the body of an exposed individual over a specified time. Therefore, dose is different from and occurs as a result of an exposure.

tise of engineers, environmental and industrial hygienists, toxicologists, epidemiologists, chemists, physicians, mathematicians, and social scientists. Exposure-assessment methodology employs direct and indirect techniques, including measurement of environmental variables (e.g., indoor-air exchange rates); personal monitoring of contaminants in the breathing zone; and use of biological markers, questionnaires, and computational modeling. Exposure assessment is an equal partner with toxicology in defining human health risk and identifying exposure-response relationships.

As relationships between particular agents and health effects have become better understood, risk-assessment methodology has evolved to estimate the likelihood that exposure to a given pollutant will produce a given health effect. As defined in the 1983 NRC report, *Risk Assessment in the Federal Government: Managing the Process*, risk assessment has four components: hazard identification, dose-response assessment, exposure assessment, and risk characterization. Figure 1 illustrates the integral role that exposure assessment plays in the risk-assessment and risk-management processes. Accurate exposure data on contaminant concentrations at the point of contact between a human and the environment are crucial to valid risk assessment.

Many advances in knowledge of exposure assessment have not been well integrated into standard risk-assessment practice. A common approach to regulation of contaminants has been to focus attention on a specific single environmental medium (e.g., air) and to deal with the problems of contamination and human contact as a one-dimensional (single-medium) problem. Although multimedia approaches to environmental problems have received increasing attention in recent years (e.g., EPA's 1986 "Guidelines for Estimating Exposures," which specify identification of the principal environmental pathways of exposure), risk-management practices generally remain dominated by single-medium and single-contaminant approaches.

## FRAMEWORK FOR ASSESSING EXPOSURES TO AIR CONTAMINANTS

Exposure assessments for airborne constituents must be considered within a framework that recognizes the potential contributions from other environmental media. Furthermore, to achieve effective risk assessment, risk management, environmental epidemiology, and diagnosis and intervention in environmental medicine, all media and routes of exposure should be assessed for the relative magnitude of their contributions before an intensive assessment of one medium is conducted. To maximize opportunities for risk management, exposure assessments should include information on the specific sources

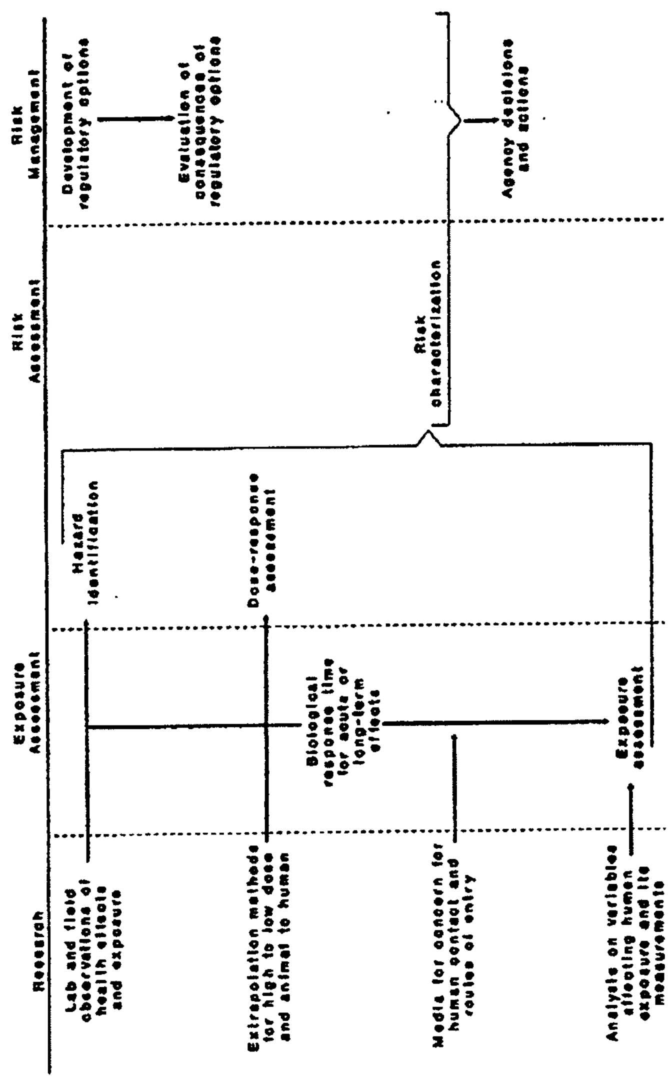


FIGURE 1 Elements of human exposure and their relationship to the process of risk assessment and risk management. (Source: Adapted from NRC, 1983a.)

of contaminants, locations of human contact with the contaminant, and environmental factors affecting the exposures to ensure that effective and appropriate mitigation measures can be formulated. Exposure data should be collected over intervals consistent with the expected biological response time to compounds; this requires knowledge of contaminant toxicity. Data on individual exposures can be integrated by summing over time (time-integrated exposure), over persons (population-integrated exposure), and over contaminants (contaminant-integrated exposure).

Studies to assess exposures to environmental contaminants, whether they are intended to improve environmental epidemiology, disease diagnosis and intervention, risk assessment, or risk management, need to consider the three principal methods of exposure assessment: personal monitoring, biological marker measurements, and indirect methods (e.g., microenvironmental concentration measurements coupled through models to time-activity data obtained from questionnaires). These methods then can be incorporated into the study design to the extent practical and necessary to meet the specific objectives of the assessment. It is not always necessary to monitor contaminant concentration in the breathing zone of each individual in a potentially exposed population. For example, if important contaminant sources and exposure locations were known from previous studies, only fixed-site monitoring data and knowledge of the frequency and duration of exposure of individuals at the contact location would be needed.

Exposure assessment has been practiced in several different disciplines, and numerous definitions and methods of estimating exposure have been developed, including those in the 1988 EPA publication, *Proposed Guidelines for Exposure-Related Measurements*.[2] These guidelines define exposure by units of mass. EPA's definition multiplies exposure (units of contaminant concentration and time) by a contact rate (e.g., breathing in units of volume per time). Time and volume units cancel in the equation, leaving mass. This is more appropriate as a definition of "dose" than of exposure, within the context described by the NRC Committee on Biologic Markers.

Because standard definitions are critical to developing coherence in the field of exposure assessment, the committee recommends that the scientific and regulatory communities, including those responsible for reviewing articles for scientific journals, use consistently the definitions of exposure and exposure assessment recommended in this report to ensure standardization across disciplines.

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[2]The EPA guidelines are being modified to incorporate new and improved approaches to understanding exposure.

## SAMPLING AND PHYSICAL-CHEMICAL MEASUREMENTS

### Quality Control and Quality Assurance

Using advanced measurement techniques in exposure studies does not in itself ensure better data. Quality-assurance (QA) programs are critical components of exposure studies; they must be established as part of initial study designs, at which point it should be decided what precision and accuracy are needed to test the study hypothesis. (Accuracy refers to the degree of agreement of a measurement with an accepted reference or true value; precision is a measure of the agreement among repeated individual measurements.)

QA activities, such as interlaboratory comparisons and measurement system audits, are carried out to ensure that the collected data achieve predetermined levels of precision and accuracy. The committee considers QA to include quality control, which comprises operational activities carried out before and during the measurement process to ensure that the accuracy and precision of data are sufficient to meet the needs of a study. An effective QA program is costly (approximately 15-25% of total study expenses) and should be considered when establishing a project's budget.

A major deficiency in the field of exposure assessment is the general lack of validation studies for most new samplers and analytical instruments. In this regard, attention should be given to the availability of reliable chemical standards (sample compounds of known composition and concentration) to use as validation references for measurement techniques. This is especially true for highly reactive compounds. These compounds often are of concern from a health perspective, and stable, known quantities can be difficult to prepare.

### Sampling Techniques and Strategy

Most advances in exposure-assessment science have occurred in the development of samplers and measurement techniques for fixed-site and personal air monitor studies; the latter have focused on activities and sources that contribute to individual and population exposures. However, new personal air sampling techniques have been underused—especially to provide data to support regulatory decision making.

The choice of a sampling strategy and a measurement method hinges on a study's specific aims and hypotheses. Physical, chemical, and biological characteristics of a pollutant dictate the method chosen to sample and measure its airborne concentration. Because a contaminant can have very different health effects in the vapor phase versus the condensed phase, care must be

exercised that the selected sampling procedure does not present a false picture of a contaminant's physical state.

Airborne contaminants can be sampled actively or passively. Active sampling uses a pump to pull airborne contaminants through a collection device. Passive sampling relies on molecular diffusion to deliver airborne contaminants to the collection medium. Passive monitors are well suited to collect long-term integrated gas and vapor samples obtained over days or weeks, and they can be extremely useful for personal or microenvironmental studies. However, long-term sampling with passive monitors often places great constraints on the sorbent, which must retain the analyte of interest without promoting unintended reactions with other adsorbed analytes. Sorbent improvements are needed to allow long-term sampling for a wide variety of analytes.

Personal air monitoring is the most direct approach for assessing human exposure to airborne pollutants. However, portability usually is attained at the expense of sensitivity (compared with fixed-site microenvironmental monitoring instruments). Personal monitors (active or passive) need to be developed for many potentially harmful airborne contaminants, including certain metals, polycyclic aromatic hydrocarbons and other semivolatile organic compounds, polar volatile organic compounds (e.g., vinyl chloride), and radon progeny. In some cases, personal monitors already exist but need to be refined, reduced in weight and size, or validated (e.g., airborne particles and certain pesticides).

Certain pollutants produce effects only at concentrations greater than a threshold value. Therefore, personal samplers of such pollutants are needed that will continuously monitor only exposures to concentrations greater than a designated threshold for community and occupational exposures.

Quiet and unobtrusive microenvironmental samplers are needed if fixed-site sampling is to be used widely; such samplers should be developed for the full spectrum of air contaminants.

New sorbents for polar volatile organic, highly volatile, and very reactive compounds are needed. Collection with sorbent sampling systems often is associated with a compromise in analytic sensitivity; this results from the large volumes used in liquid desorption techniques. Procedures such as supercritical fluid extraction that permit desorption with a minimum of dilution need to be developed.

**Instrumental Techniques**

Many advances have been made in instrument design, operation, and experimental deployment during the past 15 years. Liquid chromatography (LC)

techniques are being used to analyze for compounds not amenable to gas chromatography (GC). In particular, ion chromatography is being used increasingly to analyze highly polar air contaminants. LC combined with mass spectrometry also is being developed into a technique to complement GC combined with mass spectrometry. The development of new types of detector configurations (e.g., ion trap mass spectrometer) has made mass spectrometry a valuable air-analysis device. Simple advances have been made for other GC and LC detectors.

Field applications of exposure-assessment methods are restricted by instrument limitations. Portable, reliable, and rugged instruments such as gas chromatographs, gas chromatograph/mass spectrometers, ion trap mass spectrometers, and electrochemical sensors are needed. Sampling methods, instruments, and software to function with these instruments also are needed to permit unattended sample collection and analyses in field settings for extended periods. A sensitive, highly specific detector applicable to numerous compounds is needed for LC. Continued improvements in LC combined with mass spectrometry are beginning to fill this gap.

## USE OF BIOLOGICAL MARKERS IN ASSESSING HUMAN EXPOSURE TO AIRBORNE CONTAMINANTS

Biological markers in an exposed individual can provide information about an original contaminant, a metabolite of a contaminant, or the product of an interaction between a contaminant agent and some target molecule or cell. As one progresses from markers of exposure to markers of health effect, variability associated with the individual becomes an increasingly significant problem.

Biological markers have been studied as a part of research on exposure to air pollutants for a limited number of compounds. Critical issues are associated with marker specificity and sensitivity to an exposure contaminant. In some cases, biological markers cannot be used without adjustments for exposures to background concentrations of contaminants from the same or other media and adjustment for seasonal or regional variation.

The use of biological markers in exposure assessment should normally be done in conjunction with personal or microenvironmental exposure-measurement techniques. Biological markers integrate all routes and sources of exposure and can provide measures of the actual dose of a contaminant an individual has received when appropriate metabolic data are available and when the relationships between times of exposure and sample collection are adequately

defined. However, the actual routes and sources of exposure cannot be detected without information on environmental contaminant concentrations.

Analytical techniques with improved chemical specificity and sensitivity for biologically significant markers are needed for exposure assessments; especially needed are flexible assays that can analyze several markers simultaneously or be readily adapted to analyze numerous markers sequentially. For such techniques, validation studies are needed to link biological markers conclusively to causative agents.

Pharmacokinetics is the quantitative description of the rates of absorption, distribution, metabolism, and elimination of a contaminant taken into a biological system. Better pharmacokinetic data are needed for an increasing number of chemicals. These data are needed to further the development and validation of sophisticated biological marker models and to further understanding of how to model multiple metabolic pathways as a function of exposure level.

## SURVEY RESEARCH METHODS AND EXPOSURE ASSESSMENT

Although there have been major advances in personal monitoring equipment and in conducting sociological studies of time use, exposure-related data on human activity patterns are in short supply. The techniques normally employed are questionnaires and recall diaries to obtain information on location and duration of human activities. Elementary principles of statistical survey design, sample selection, and question format often are ignored in questionnaires and surveys used by exposure analysts. Collaboration of social scientists having expertise in survey statistics with exposure analysts can help to develop more appropriate questionnaires, to limit the effects of biased questions, and to validate survey instruments before their use in the field.

Far more attention needs to be given to the design of survey research in exposure studies. Exposure analysts need to employ the expertise of specialists in survey statistics and the measurement of human time-activity patterns through the use of questionnaires. Improvements are needed in the reliability (precision) and validity of survey results, especially with regard to estimates of frequency or duration of exposure. The estimation of long-term exposures presents challenges yet to be addressed by survey researchers.

In addition to resource-intensive surveys of large populations, far more use should be made of well-designed, but less-expensive, sequential or one-time studies done at the community level. Such surveys could be especially important for personal-exposure monitoring studies. In addition, a series of small

benchmark surveys of "normal" situations or environments are needed to help establish baselines for other studies (e.g., studies of time activity in "healthy" buildings for comparison with similar studies in "sick" buildings).

## MODELS USED IN ASSESSING HUMAN EXPOSURE TO AIRBORNE CONTAMINANTS

Mathematical models use systems of equations to quantify and explain the relationships between air-pollutant exposure and important variables, such as emission rates from contaminant sources, as well as for estimating exposures in situations where direct measurements are unavailable. These models are derived from assumptions and approximations that permit complex physical-chemical-behavioral problems to be represented by mathematical formulations.

Models considered by the committee were classified into two broad categories: those that predict exposure (in units of concentration multiplied by time) and those that predict concentration (in units of mass per volume). Exposure models obviate extensive environmental- or personal-measurement programs by providing estimates of population exposures that are based on small numbers of representative measurements. Although concentration models are not truly exposure models, the output of concentration models can be used to estimate exposures when combined with information on human time-activity patterns.

To improve the development and validation of models, measurements are needed of the concentrations of airborne pollutants in workplaces, homes, and other microenvironments. Simultaneous measurements of critical independent variables, such as source-emission rates and indoor-ventilation rates, are also needed for models. Concentration gradients within defined microenvironments also need to be accurately measured.

Validation studies are needed for many existing models. In particular, immediate efforts are needed to validate the models used for decision making by EPA, ATSDR, and others about public and occupational health and to tailor the models to relate to the actual situations that can result in large population exposures. Valid emission-rate models are needed to provide better estimates for multicomponent mixtures. Validated outdoor-dispersion models are needed to predict concentrations in complex terrain and to provide accurate exposure estimates for down- and up-gradient terrain conditions.

The same data set used to develop a model cannot be used to refine and validate it; new, independent data are required. In addition, all assumptions used in developing a model should be documented explicitly. Care should be

taken by investigators in any field-monitoring program to integrate measurements with modelers' information needs so that the requisite model input data are obtained or the measurement results can be used to test, refine, or validate appropriate models.

Little work has been done to model very short-term exposures (peak exposures) and gradients for dispersion, deposition, and ventilation in indoor environments. Measuring and modeling the temporal patterns of source strength as a function of readily identifiable or measurable source characteristics is a critical step in that process. In addition, more work is needed to model the relationship of indoor-air quality to the composition of the outdoor air.

**Concentration Models**

New developments in outdoor-dispersion models have improved prediction of the average and time-varying concentrations to which individuals are exposed. Receptor models can be compared with dispersion models as a means of checking the predictions of both models. They also can be used to identify sources of exposure. In many cases, however, data describing the source characteristics are not available on the time scale for which the model predictions are needed. Such mismatches of the time scale of the measurements with the time scale of the models impede model development, validation, and application to new exposure scenarios.

Source-emission models are available to predict mass-emission rates for a variety of dynamic and steady-state emission problems. The available emission models allow the estimation of downwind exposure for continuous and catastrophic releases of pure compounds or binary mixtures. However, these models have not been validated. Dense cloud dispersion models are available to estimate downwind exposure for heavier-than-air vapor or aerosol releases; they also have not been validated.

**Exposure Models**

Models for predicting exposures to populations have been developed but have not been adequately validated. Limited validation studies of the EPA's "Simulation of Human Air Pollution Exposure Model," for example, show that the average exposure values are well predicted but also show substantial discrepancies in the tails of the distribution. Further development and validation of these models are warranted. Exposure models used for regulatory decision

making should be developed and validated for microenvironments where significant exposures occur.

## FUTURE DIRECTIONS FOR EXPOSURE ASSESSMENT

Air-exposure reduction strategies for a given contaminant should first consider exposures due to all media. If other media are found to contribute significantly to the total exposure even after air exposures are reduced, agencies responsible for or experienced with the other media should be apprised of the issue and be actively involved in the development of integrated exposure-reduction strategies.

Unless the health effect of a contaminant is unique or the source of the contaminant exposure is well characterized, it is difficult to relate an exposure to a health effect for one of a group of contaminants present in specific microenvironments. When a contaminant does not have a unique health effect, it is necessary to identify those situations where populations can have substantial exposures. Once the exposure is assessed, that information should be used to perform studies to establish the magnitude of the health outcome from exposure in those situations.

Attempts to assess human exposure to air contaminants have achieved varying degrees of success. It is easy to find flaws with any exposure study when we are only beginning to understand the ways in which human activity affects exposures of individuals and populations. It is clear, however, that the field of air contaminant exposure assessment has advanced significantly as a result of indoor-air pollution studies. Further progress will be achieved as exposure study designs more completely address and rank potential contributions from all environmental media to all relevant microenvironments.

# *Assessing Human Exposure to Airborne Contaminants*

# 1

# *Principles of Exposure Assessment*

## INTRODUCTION

Since the early 1970s, when federal regulatory agencies first focused their attention on the association of cancer and other chronic diseases associated with human exposure to toxic agents, rapid advances in bioassay techniques and other test methods have made it possible to discern relations between particular agents and cancer and other health effects. Risk assessment is a method for estimating the likelihood that a given pollutant will have a given health effect. Risk assessment has four components: hazard identification, dose-response assessment, exposure assessment, and risk characterization (NRC, 1983a). Advances in hazard identification and dose-response assessment have been successfully incorporated into risk-assessment practice. Advances in analytic instrumentation permit the detection of chemicals at lower and lower concentrations and these make it possible to detect the presence of chemicals that would have been missed earlier. Also, advances and improvements in mathematical and statistical manipulation of data have been major contributors to improvement in the practice of risk assessments. However, accurate data on exposure, i.e., contaminant concentrations at the boundary between a human and the environment and the duration of contact, are also crucial to valid risk assessment, but advances in exposure assessment have not been fully integrated into standard risk-assessment practice.

Exposure assessment has seen important conceptual and practical advances. Perhaps the most fundamental has been the recognition that exposures to various contaminants can occur through contact of any tissue with any environmental medium at any time, and in all sorts of venues. That might seem obvious, but in major environmental regulations, exposures to contaminants have been—and to a large degree still are—thought of in the terms of 8-hour workplace exposures and 24-hour outdoor exposures of a "standard" 70-kg man. Such definitions assume the presence of a contaminant in a particular medium

(or microenvironment) just as they assume the presence of the person and the contact with that medium in that microenvironment. In fact, indoor concentrations of some pollutants can be higher than outdoor concentrations, most people spend far more time indoors than outdoors, and different population groups (e.g., young children and older persons) have different patterns of sensitivity and activity, which affect their likelihood of and responses to exposure.

The national environmental-policy implications of those findings could be enormous. For example, if indoor sources of airborne benzene were acknowledged, and it were determined that the average person's major exposure occurred indoors, rather than outdoors, the allocation of hundreds of millions of dollars for control of industrial emissions of benzene might appear less than optimal. The same could well be true of a number of other major elements (such as $NO_2$ from stoves) of concern to national environmental policy associated with substantial exposures.

The Committee on Advances in Assessing Human Exposure to Airborne Pollutants was established by the National Research Council's Board on Environmental Studies and Toxicology to review important new developments in exposure-assessment instrumentation and methods that have arisen in pollution-related research, occupational medicine, and other disciplines over the last 10-15 years, especially as they apply to individual human exposures to airborne toxic substances. The committee's work was sponsored by the Agency for Toxic Substances and Disease Registry (ATSDR), whose mandate is to prevent or mitigate adverse human health effects and diminution in quality of life resulting from exposure to hazardous substances in the environment. In response to its charge and to national needs for improved understanding about exposures to environmental hazards, the committee has reviewed the new developments and developing technologies in exposure assessment, identified knowledge and technological gaps, and recommended research and development to fill those gaps. In this report, the committee also presents a conceptual framework for the science of exposure assessment and illustrates, with a series of case studies, how exposure assessments can be (and have been) properly and improperly applied and conducted. However, it was not within the committee's charge to perform an exhaustive study on the proper application and further development of techniques to assess exposure to any specific contaminant.

This chapter introduces the basic principles and definitions of exposure assessment. Chapter 2 presents the framework for conducting exposure assessments, the quantitative relationship among source and receptor characteristics, and the basic components of exposure assessment and how it may be employed. Sampling and physical and chemical measurements are discussed

in Chapter 3, biological markers in Chapter 4, questionnaires and survey issues in Chapter 5, and modeling techniques and instruments in Chapter 6. Chapter 7 contains a number of airborne-contaminant case studies that illustrate the application and misapplication of exposure assessment. The summaries of Chapters 1 and 2 contain general conclusions and recommendations. The summaries of Chapters 3 through 6 contain conclusions and recommendations relevant to the exposure assessment methods discussed in each chapter. Such methods can be incorporated into a study design to the extent practical and necessary to meet the specific objectives of the assessment. Conclusions presented at the end of each case study in Chapter 7 focus on broad implications for the discipline of exposure assessment, notable advances, and remaining needs.

## BACKGROUND

Environmental contaminants found in the community or occupational settings long have been thought to be related to a wide range of adverse health and nuisance effects in humans. In the course of daily activities, humans are exposed to a variety of environmental contaminants through the air they breathe, water and beverages they drink, food they eat, and materials that contact their skin. These events occur in many settings—indoors (e.g., residential, industrial, occupational, and transportation) and outdoors. An exposure to a contaminant is defined as an event that occurs when there is contact at a boundary between a human and the environment with a contaminant of a specific concentration for an interval of time. Thus, an exposure has units of concentration and time. This definition is consistent with definitions of exposure presented in other NRC reports and is discussed in greater detail in Chapter 2.

Total human exposure accounts for all exposures a person has to a specific contaminant, regardless of environmental medium (air, water, food, and soil) or route of entry (inhalation, ingestion, and dermal absorption) (Lioy, 1990). For media other than air, the time increment could be infinitesimal, such as that incurred during the act of drinking a glass of water. It is a necessary concept to carrying out risk assessments or health studies for a pollutant. Sometimes total exposure is used incorrectly to refer to exposure to all pollutants in an environment. Total exposure to more than one pollutant should be stated explicitly as such.

Assessing the total exposure of an individual or population involves numerous techniques to identify the contaminant, contaminant sources, environmental media of exposure, transport through each medium, chemical and physical